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AUTO BLACK EXPANSION METHOD AND APPARATUS FOR AN IMAGE SENSOR

Field of the Invention

The present invention relates to metal oxide semiconductor (MOS) image sensors and, more particularly, to auto black expansion systems in such image sensors.

Background of the Invention

Integrated circuit technology has revolutionized various fields, including computers, control systems, telecommunications, and imaging. One field in which integrated circuitry is widely used is video imaging. Different types of semiconductor imagers include: charge coupled devices, photodiode arrays, charge injection devices, and hybrid focal plane arrays. Many of these devices include pixels that are arranged in sensor arrays to convert light images into electrical signals.

Examples of MOS imaging devices are detailed in "A ¼ Inch Format 250K Pixel Amplified MOS Image Sensor Using CMOS Process" by Kawashima et al., IEDM 93-575 (1993), and "A Low Noise Line-Amplified MOS Imaging Devices" by Ozaki et al., *IEEE Transactions on Electron Devices*, Vol. 38, No. 5, May 1991. In addition, U.S. Patent No. 5,345,266 to Denyer, titled "Matrix Array Image Sensor Chip," describes a MOS image sensor. The devices disclosed in these publications provide a general design approach to MOS imaging devices. In addition, MOS approaches to color imaging devices are described in "Color Filters and Processing Alternatives for One-Chip Cameras," by Parulski, *IEEE Transactions on Electron Devices*, Vol. ED-32, No. 8, August 1985, and "Single-Chip Color Cameras With

Reduced Aliasing" by Imaide et al., *Journal of Imaging Technology*, Vol. 12, No. 5, Oct. 1986, pp. 258-260 .

Image sensor circuitry generally includes circuits for performing black level calibration and automatic gain control. Black level calibration attempts to eliminate the portion of the image signal that exists when no light is being detected, thus allowing for a truer zero reference signal so that the later signal processing is improved. After the black level calibration has been performed, automatic gain control amplifies the video signal at a controlled level so as to utilize more of the available signal amplification range. The combination of the black level calibration and automatic gain control can be said to form one type of an "auto black expansion" method. One prior art circuit that addresses issues related to these processes is shown in U.S. Patent No. 4,187,519 to Vitols et al. Figures 1, 2, 3, 4, 5, 6 and 7 of Vitols et al. have been reproduced herein as FIGURES 1, 2A, 2B, 2C, 2D, 2E, and 2F, respectively.

Vitols et al. disclose a circuit that is designed to provide a video contrast expansion system. As illustrated in FIGURE 1, a sequence of video pixel data representative of an image is developed by a signal source 11, which may be, for example, a radar, an IR (infrared) sensor or a TV (television) camera. This pixel data is applied to an I-getter (intensity getter) 13 and to a delay circuit 19. An initialize command signal from the source 11 initializes the operation of the I-getter 13 before or during the time that the sequence of pixels is being generated by the source 11.

The I-getter 13 searches the input sequence of pixels (designated as new data or ND) to determine bias and gain intensity parameters. A bias function generator 15 is automatically adjusted by the bias parameters to develop pixel bias correction signals. In a similar manner a gain function generator 17, which is similar in structure and operation to the generator 15, is automatically adjusted by the gain parameters to develop pixel correction signals.

In its operation the I-getter 13 reduces and transforms the input sequence of pixels into a reduced number of bias parameters and a reduced number of gain parameters. Each of the function generators 15 and 17 smoothly fills in or shades in its associated widely spaced apart parameters (bias or gain) by double linear interpolations to produce its associated correction signals (bias or gain). Each sequence of correction signals is equal to the number of pixels in the input sequence of pixels.

It takes time for each of the function generators 15 and 17 to get sufficient parameter data in before it can start computing its associated correction signals. Furthermore, it takes additional time before each of the function generators 15 and 17 compute its associated correction signals. This combined delay time is offset by the delay circuit 19 which synchronizes the time of occurrence of the sequence of pixels at the output of the delay circuit 19 with the time of generation of the pixel bias correction signals and pixel gain correction signals.

The computed pixel bias correction signals are respectively subtracted in a combiner or subtractor 21 from the delayed or synchronized sequence of pixels to selectively lower the minimum values in associated groups of pixels in the delayed sequence of pixels to very close to zero. The minimized output of the combiner 21 is respectively multiplied in a multiplier or AGC (automatic gain control) circuit 23 to selectively expand the maximum amplitudes in the associated groups of pixels at the output of the combiner 21 to near the saturation level of the electronics of the system of FIGURE 1. The output of the AGC circuit 23 can be applied to a display generator (not shown) to generate an enhanced picture of the image in which the video contrast of the image has been substantially expanded in two directions (minimum and maximum values of contrast).

The pixel data at the output of the signal source 11 may have a very narrow dynamic range of contrast, making it extremely difficult to discern objects in areas of lower contrast if directly viewed at the point. However, by the operation just explained, the pixel data at the output of the AGC circuit 23 has its dynamic range of contrast selectively expanded or stretched from near minimum to near maximum, making objects originally in low areas of contrast now clearly discernible when displayed.

FIGURES 2A-2F illustrate some of the possible operations that the circuit of FIGURE 1 can perform on a one-dimensional signal. Such operations are analogous to those performed on a two-dimensional signal since a two-dimensional signal is essentially comprised of a vertical plurality of horizontal one-dimensional signals.

FIGURE 2A illustrates an exemplary one-dimensional signal I(x) comprised of a sequence of 256 pixels. Although I(x) is shown as an analog signal it is a sequence of 256 intensity (I) points of varying amplitudes. Note that I(x) varies over a fairly wide intensity range from an amplitude of 630 (I_{sat} or the intensity saturation level of the system) to an amplitude of about 50 at the low end.

It may be desired in some applications to look for small, rather than large, amplitude deviations from nominal. For example, if the intensity variations in the incoming signals I(x) of FIGURE 2 represent pixels or intensity points of a scene, very high intensity portions of I(x) would ultimately develop very bright portions in a picture, and very low intensity portions of I(x) would ultimately develop very dark portions of the picture. However, a human observer or operator may not necessarily be interested in very high or very low intensity levels in the incoming signal I(x). Rather, an observer may only be interested in small variations of intensity in I(x), whether contained in very high, very low and/or intermediate levels of intensity in I(x). This is due to the fact that the small variations of intensity in I(x) can define the details of a scene or image sufficiently to possibly enable an observer to identify what is happening or contained in the picture.

By using a conventional contrast enhancement technique, an observer may be unable to discern what is contained in picture areas of small intensity variations. It is to the correction of this problem that the circuit of FIGURE 1 is directed. To illustrate, assume that the low intensity region of pixels between 100 and 200 in FIGURE 2 represents the signal that is coming from the inside of a dark cave. The brightest pixel in the 100-200 region of pixels is dark in comparison with the other high intensity or bright pixels in FIGURE 2. An observer may be looking for the glint of light on a gun barrel inside that cave. If the dynamics of the signal in that 100-200 pixel region remain unchanged, an observer would not be able to see that glint of light on that gun barrel. However, if the gain of the signal in the 100-200 pixel region (where the amplitude of the signal is very low) could be increased so that variations of the signal show up to substantially the fullest extent possible without saturating the electronics of FIGURE 1, the human observer could more readily determine what was inside the cave. It should be noted that a resultant picture would not look like a normal picture since the inside of the cave would be just as bright as what surrounds the cave on the outside. However, the intent of the circuit of FIGURE 1 is to brighten everything to the fullest dynamic range, so that an observer can see what is happening or contained in a resultant picture.

FIGURE 2B illustrates a possible guide as to what may be done to increase the dynamic range of I(x) of FIGURE 2A. As shown, FIGURE 2B illustrates a plurality of eight local data regions, each 32 pixels in length, which respectively encompass contiguous 32-pixel long portions of I(x). In each data region the brightest (or largest intensity) and darkest (or smallest intensity) parts of the

associated portion of I(x) are determined. The largest and smallest intensity values found in each data region are used to form horizontal ceiling (C) and floor (F) values for each pixel across that region. Thus, the sequence of ceiling values found in the respective data regions forms a ceiling function of X values, designated C(x), while the sequence of floor values found in the respective data regions forms a floor function of X values, designated F(x), for the included portions of I(x). FIGURE 2C shows just F(x) the floor function of FIGURE 2B. As shown, F(x) is comprised of the segmented sequence of minimum values across the respective regions of FIGURE 2B.

As described, a first possible operation that can be performed to maximize the dynamic range of I(x) is to subtract F(x) from I(x) to produce the wave form shown in FIGURE 2D. It can be seen in FIGURE 2D that the amplitude of the signal I(x) of FIGURE 2A is substantially reduced, while still substantially retaining the intensity variations of FIGURE 2A.

As also described, the next possible operation that can be performed is to expand the amplitude of the signal I(x)-F(x) of FIGURE 2D by adjusting the gain in the first data region (0-32), second data region (32-64). third data region (64-96) etc.—each gain adjustment being independent of the others—so that the maximum value of the signal in each data region go all the way up to the maximum permissible level or saturation level (I_{sat}). FIGURE 2E illustrates a piecewise constant gain function G(x) that would independently adjust the amplitude in each segment or data region up to the saturation level. This piecewise constant gain function would be determined by the value of the saturation intensity (I_{sat}) divided by the difference between the C(x) and F(x) functions.

FIGURE 2F illustrates the result of multiplying the function of FIGURE 2D by the gain function of FIGURE 2E. This multiplication raises the maximum value in each data region up to the saturation level. However, Vitols et al. describe FIGURE 2F as being very unsatisfactory because of the discontinuities or, places where the amplitude of the signal rises or falls vertically. Although the full dynamic range of the signal is obtained in each data region, the resultant signal shown in Figure 2F is very bumpy. So the overall information that an operator may be looking for in the signal may be totally lost in the discontinuities. If the one-dimensional wave form of Figure 2F were applied to a two-dimensional picture, a very strong checkerboard pattern would result, which would distort the operator's perception of a picture or image to the point where he probably could not discern what he was looking at. Vitols et al. go on to explain how the discontinuities shown in

FIGURE 2F can be eliminated by smoothing the signal functions F(x) and G(x) from one data region to another. This smoothing operation is described further in the Vitols et al. patent, but will not be discussed further herein.

One of the drawbacks of the Vitols et al. circuit is that it requires a complex sequence of operations to determine the desired adjustment functions for the system. As described, the I-getter (as illustrated in Figure 12 of Vitols et al.) requires two shift registers for every data cell used in an output picture. In addition, a large number of switching points capable of switching out each of the data cells for separate comparator operations must be used. In addition, during the comparator operations the comparator voltage level to which the incoming pixel signals are compared may be constantly shifting. In addition, as further described in Vitols et al., it takes time for each of the function generators to get sufficient parameter data in before the function generators can start computing the associated correction signals. Furthermore, it is also stated that it takes additional time before each of the function generators can compute its associated correction signals. This combined delay time must be offset by a delay circuit which synchronizes the time of occurrence of the sequence of pixels with the time of generation of the pixel bias correction signals and pixel gain correction signals.

The present invention is directed to a circuit that overcomes the foregoing and other problems in the prior art. More specifically, the present invention is directed to an auto black expansion method and apparatus for an image sensor that uses a simplified digital control system and does not require additional shift registers for the pixel signals or continual shifting of input comparator levels during a given field.

<u>Summary of the Invention</u>

A simplified digital control method and apparatus for auto black expansion in an image sensor is disclosed. Within the auto black expansion method, black level calibration is used to eliminate the unused lower portion of the signal range, and automatic gain control is used to amplify the video signal at a controlled level so as to utilize more of the available signal amplification range. In the preferred embodiment, the black level calibration is performed by an auto black expansion circuit, and the gain adjustment is performed by an automatic gain control circuit.

In accordance with one aspect of the invention, the simplified digital control system is based on a count of the number of pixels with signal intensities that occur below selected levels. Preferably, a black level voltage and a mid-level voltage comprise the selected levels to which the pixel intensities are compared. Since the

control system is based on a count of pixel intensities below a certain level, objects within the sensed image can move around without generally changing the total pixel count or requiring shifting in the black level or gain adjustment parameters. In addition, the storing of an absolute count provides for simpler processing circuitry and reduces the likelihood of errors that occur when multiple analog signal levels must be stored.

In accordance with another aspect of the invention, for each of the black level and mid-level comparisons, a single comparator can be used to read the output signals from the pixels and store the pixel count in a single counter. This reduces the parts count relative to a method that requires individual storage areas for each pixel in a given field. This also reduces the wiring requirements and control circuit complexity. In addition, these factors also contribute to increasing the speed with which the process as a whole may be performed.

In accordance with another aspect of the invention, precise adjustments may be made to the auto black expansion and automatic game control circuits by using a control signal with a sufficient precision. Preferably, a control signal is used having at least eight bits. The level of adjustment may be based on a calculation of the difference between the counted number of pixels below a selected level and the desired number of pixels.

In accordance with another aspect of the invention, an adjustment to the auto black expansion or the automatic gain control is made at the end of each field. By making the adjustments in between fields, linear amplification is maintained within a given field and the chances for processing errors during a given field are reduced.

Brief Description of the Drawings

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a schematic diagram of a prior art circuit for expanding the video contrast of an image;

FIGURES 2A-2F are a series of timing diagrams illustrating the operation of the prior art circuit of FIGURE 1;

FIGURE 3 is a schematic diagram of a black level calibration and automatic gain control processor according to the present invention;

FIGURES 4A-4C are a series of timing diagrams illustrating the operation of the circuit of FIGURE 3;

FIGURES 5A-5C are a series of flow diagrams illustrating the method of the present invention.

Detailed Description of the Preferred Embodiment

With reference to FIGURE 3, black level calibration and automatic gain control circuiting are shown for use in a single-chip CMOS imaging sensor. The automatic gain control amplification and black level calibration are performed according to the black level expansion method of the present invention. As will be explained in more detail below, the novel method auto black expansion uses a simplified digital control method for the signal processing. The black level calibration attempts to eliminate the portion of the signal that exists when no light is being detected, as is known in the art, thus allowing for a truer zero reference signal so that the later signal processing is improved. The automatic gain control amplifiers (AGC) amplify the signals at a controlled level for further processing.

As illustrated in FIGURE 3, an auto black expansion circuit 402 performs the black level calibration and the automatic gain control circuit 404 performs the gain adjustment. A signal SIG1' is processed by the digitally controlled auto black expansion circuit 402. The auto black expansion circuit 402 shifts the voltage level of the signal SIG1' by a level voltage V_{ABE}. The output of the auto black expansion circuit 402 is then processed by a digitally controlled automatic gain control circuit 404. Both the auto black expansion circuit 402 and automatic gain control circuit 404 are analog circuits that are controlled by digital signals. Automatic gain control circuit 404 amplifies the input signal (SIG1' - V_{ABE}) according to a desired gain level G_{AGC}. The output signal level SIG1" is thus illustrated by the following equation.

$$SIG1'' = (G_{AGC})(SIG1' - V_{ABE}) \qquad (1)$$

Two comparators 406 and 408, and a digital controller 410, provide a digital control feedback loop for the auto black expansion circuit 402 and the automatic gain control circuit 404. The noninverting inputs of the comparators 406 and 408 each receive a signal SIG1" that is output from the automatic gain control circuit 404. The inverting input of the comparator 406 receives a desired black signal level V_{BLK} while the inverting input of the comparator 408 receives a desired mid-level voltage V_{BAR}.

The outputs of the comparators 406 and 408 are provided to a digital controller 410. Digital controller 410 includes two counters 412 and 414. The output from comparator 406 is received by a counter 412, while the output from comparator 408 is received by a counter 414. Digital controller 410 provides a digital control signal 422 to auto black expansion circuit 402, and a digital control signal 424 to automatic gain control circuit 404. In a preferred embodiment, the digital control signals 422 and 424 are each 8-bit control signals.

FIGURES 4A-4C are timing diagrams illustrating the general operation of the circuitry of FIGURE 3. FIGURE 4A is an intensity diagram similar to the intensity diagram illustrated in the prior art FIGURE 2A. For illustrative purposes only, the pixel signals in FIGURE 4A are provided in a step-function type format. It will be recognized that an actual intensity diagram would be much less uniform, such as that illustrated in FIGURE 2A. The step-type format is intended only to simplify the following example with respect to the digital pixel counting method of the present invention.

FIGURE 4A is illustrative of an entire field of 1024 pixels. It will be recognized that in an actual embodiment, a field may contain any number of pixels. The pixels of FIGURE 4A have intensities according to the following table.

Pixel Numbers	Intensity
1-100	700
101-200	900
201-300	1100
301-400	800
401-500	700
501-524	600
525-624	800
625-724	1000
725-824	1200
825-936	1000
937-1024	800

FIGURE 4A also illustrates a dotted-line level V_{BLK} at a level of 50 and a mid-level voltage V_{BAR} at a level of 550. The voltage level V_{BLK} represents a

desired black level to which the auto black expansion circuit 402 will shift the lower levels of the signal SIG1'. The level V_{BAR} represents a desired mid-level for which the automatic gain control circuit 404 adjusts the amplification so that a certain number of processed pixel signals are above and below the desired mid-level. As will be described in more detail below, auto black expansion circuit 402 and automatic gain control circuit 404 are digitally controlled and only operate to shift the signal levels in between fields.

The digital controller 410 maintains a count of the number of adjusted pixels signals below the desired black level V_{BLK} and the desired mid-level V_{BAR}. The desired number of adjusted pixel signals below the black level is designated as a number N_{BLK}, and the desired number of adjusted pixel signals below the mid-level are designated as a number N_{BAR}. In the example of FIGURE 4A, the desired number of pixels N_{BLK} below the signal level V_{BLK} is equal to 24. The intensity diagram of FIGURE 4A has been conveniently structured for purposes of the present example to have exactly 24 pixels (numbered 501-524) that are conveniently at a lower intensity level than the rest of the pixels.

As illustrated during the first field illustrated in FIGURE 4A, there are no pixel signals below the desired black level V_{BLK}. Thus, through a process that will be described in more detail below, during the second field illustrated in FIGURE 4B, the auto black expansion circuit 402 shifts the signal SIG1' down by an adjustment level V_{ABE}. As illustrated in FIGURE 4B, this causes the intensity diagram of the second field (in which the sensed image is the same as that of FIGURE 4A) to be level shifted down such that the pixels 501-524 are now below the desired black level V_{BLK}. As will be described in more detail below, rather than setting the number N_{BLK} at a single number of acceptable pixels, a range may be set. For example, the acceptable range may be set to be above a selected lower number N_{BLK1} (e.g., 16) and below a selected upper number N_{BLK2} (e.g., 32).

The desired number $N_{BLK} = 24$ pixels below the desired black level represent approximately 2.3% of the total 1024 pixels. In the preferred embodiment, the actual desired number of pixels below the black level V_{BLK} is closer to 0.5%. In the example of FIGURE 4B, the desired number of pixels below the black level V_{BLK} was achieved in a single shift between fields, however, in an actual embodiment, several level shifts, both up and down, may be required to achieve the desired number of adjusted pixel signals below the desired black level V_{BLK}.

Once the desired number of adjusted pixel signals below the black level V_{BLK} has been achieved, the gain is adjusted by the automatic gain control circuit 404 so as to raise the approximate mid-level intensity to the desired mid-level V_{BAR}, as illustrated in FIGURE 4C. As illustrated in FIGURE 4C, during the third field, the intensities of the signals of FIGURE 4B have been amplified by a level of approximately X 2. In an actual embodiment where, for example, some of the pixels 501-524 might not all be at the zero intensity level, some of them might be amplified to be above the desired black level V_{BLK}, thus shifting the digital count in counter 412, and requiring further adjustment of the adjustment level V_{ABE} in future fields. One of the advantages of the method of the present invention is that as long as the same objects and intensities remain in the image field, approximately the same number of pixels at a given intensity should remain, and the level V_{ABE} and the gain G_{AGC} should not require further adjustment.

The intensities of the pixels of FIGURE 4C are at levels according to the following table:

Pixel Numbers	Intensity
1-100	200
101-200	600
201-300	1000
301-400	400
401-500	200
501-524	0
525-624	400
625-724	800
725-824	1200
825-936	800
937-1024	400

Thus, as illustrated in FIGURE 4C, with respect to the desired mid-intensity level V_{BAR} which is set at 550, approximately 512 pixels are above the desired mid-level, while approximately 512 pixels are below the desired mid-level. In the present example, the desired number of pixels N_{BAR} below the desired mid-level V_{BAR} is set to be 512, so that as long as the same pixel level intensities remain in future fields

(e.g., objects moving within the fields but not leaving the image), the gain level G_{AGC} will not require further adjustment. As will be described in more detail below, as the sensed image changes, the voltage level V_{ABE} and the gain level G_{AGC} may be adjusted in between fields according to the method of the present invention.

The number N_{BAR} may represent a median value, as in the present example, or may be set at a different number. Also, similar to as was described above for the number N_{BLK}, the desired number of pixels N_{BAR} for the number of pixels below the desired mid-level may also be set as a range rather than a single number. For example, the desired number of pixels may be set to be above a lower number N_{BAR1} (e.g., 504) and below an upper number N_{BAR2} (e.g., 520).

FIGURES 5A to 5C are flow diagrams further illustrating the method of the present invention. As illustrated in FIGURE 5A, at a point A, a new field begins, and at a block 500 the counter 412 is reset. At a block 502, a first processed pixel signal is read as part of the signal SIG1". At a decision block 504, comparator 406 outputs a signal indicating whether the processed pixel signal SIG1" is less than signal level V_{BLK}. If the signal SIG1" is less than the signal V_{BLK}, the comparator 406 will output a low signal, and at a block 506, counter 412 will be incremented by +1. If the signal SIG1" is not less than the signal V_{BLK}, the comparator 406 will output a high signal, and the routine will continue to a decision block 508.

At decision block 508, a determination is made as to whether the most recent pixel signal came from the last pixel of the field. This determination is most likely made according to a timing control signal (not shown) from the main processing circuitry of the system. If the pixel signal was not the last pixel from the field, at a block 510, the routine increments to the next pixel and returns to block 502 to read the next pixel signal as part of the processed pixel signal SIG1". If the last pixel in the field has been read, the routine proceeds to a point C, that will be described in more detail below with respect to FIGURE 5C.

FIGURE 5B illustrates a process similar to that of FIGURE 5A. In the preferred embodiment, the routines of FIGURES 5A and 5B are run simultaneously, although in an alternate system parts or all of the routines could be run sequentially. As illustrated in FIGURE 5B, at the beginning of a field at a point B, counter 414 is reset at a block 520. At a block 522, the processed pixel signal from processed signal SIG1" is received by comparator 408. At a decision block 524, the comparator 408 outputs a signal that indicates whether the processed pixel signal has a value less than the desired mid-level V_{BAR}. If the processed pixel signal is less than the level V_{BAR},

the comparator 408 outputs a low signal, and at a block 526, counter 414 will be incremented by +1. If the processed pixel signal is not less than the level V_{BAR}, the comparator 408 outputs a high logic level, and the routine proceeds to a decision block 528.

At decision block 528, a determination is made as to whether the last pixel in the field has been read. If the last pixel in the field has not been read, the routine proceeds to a block 530 where the routine increments to the next pixel and returns to block 502 to read the next processed pixel signal. If the last pixel in the field has been read, the routine proceeds to a point C that will be described in more detail below with respect to FIGURE 5C.

As illustrated in FIGURE 5C, from a point C, the routine proceeds to a decision block 550. At decision block 550, digital controller 410 determines whether the counter 412 number of pixels counted below the level V_{BLK} is less than a desired number N_{BLK1}. The number N_{BLK1} represents a desired threshold number of pixels below which adjustment of the level V_{ABE} is desired to shift the overall level of the intensity diagram, as was illustrated in the shift between FIGURES 4A and 4B. If the counter 412 total is less than the number N_{BLK1}, the routine proceeds to a block 552, where the level V_{ABE} is decreased by a determined increment, and the routine proceeds to a point D. The determined increment may be fixed or may be based in part on the difference between the counter 412 total and the number N_{BLK1}, or some similar algorithm indicating the magnitude of the desired shift. If the counter 412 total is not less than the number N_{BLK1}, the routine proceeds to a decision block 554.

At decision block 554, the routine determines whether the counter 412 total is greater than a number N_{BLK2}. The number N_{BLK2} represents a desired threshold number of pixels in counter 412 above which an upward increase adjustment of the level V_{ABE} is desired. The number N_{BLK2} may be the same as the number N_{BLK1}. If the counter 412 total is greater than the number N_{BLK2}, at a block 556, the level V_{ABE} is increased by a determined increment, and the routine proceeds to a point D. The determined increment may be fixed or may be based in part on the difference between the counter 412 total and the number N_{BLK2}, or some similar algorithm indicating the magnitude of the desired shift. If the counter 412 total is not greater than the number N_{BLK2}, then the routine proceeds to a decision block 558.

The process for adjusting the gain G_{AGC} begins at decision block 558. It should be noted that the gain G_{AGC} is only adjusted once it has been determined

through blocks 550-556 that the level V_{ABE} has already been adjusted to an acceptable level.

At decision block 558, the digital controller 410 determines whether the counter 414 total is less than a desired number N_{BAR1}. The number N_{BAR1} represents a desired threshold number of pixels below the level V_{BAR}, below which a decrease in the gain G_{AGC} is desired. If the counter 414 total is less than the number N_{BAR1}, the routine proceeds to block 560, where the gain G_{AGC} is decreased by a determined increment, and the routine proceeds to a point D. The determined increment may be fixed or may be based in part on the difference between the counter 414 total and the number N_{BAR1}, or some similar algorithm indicating the magnitude of the desired adjustment. If the counter 414 total is less than the number N_{BAR1}, then the routine proceeds to a decision block 562.

At decision block 562, the digital controller 410 determines whether the counter 414 total is greater than a threshold number N_{BAR2}. The number N_{BAR2} represents a threshold number of pixels above which an increase in the gain G_{AGC} is desired. If the counter 414 total is greater than N_{BAR2}, the routine proceeds to a block 564 where the gain G_{AGC} is increased by a determined increment and the routine proceeds to a point D. The determined increment may be fixed or may be based in part on the difference between the counter 414 total and the number N_{BAR2}, or some similar algorithm indicating the magnitude of the desired shift. If the counter 414 total is not greater than the number N_{BAR2}, the routine proceeds to a point D. The point D is illustrated in FIGURES 5A and 5B as a starting point for those routine at the beginning of a new field.

It will be appreciated that the greatest advantage of the auto black expansion and automatic gain control system of the above-described invention is that it is operated with a simplified digital control method that is faster, more accurate, and requires fewer circuit components than prior art methods. By utilizing a digital count of the number of pixels below selected levels, the speed of processing is increased, and the required circuit components are reduced to a comparator and a counter. In addition, by using an 8-bit or higher control signal, precise adjustments can be made to the analog black level adjustment and automatic gain control circuits. In addition, by making the adjustments between the fields after the pixel counts have been completed, the timing of the adjustments are simplified and the chances for errors in mid-field adjustments are reduced. In addition, completely linear amplification is achieved within a given field.

While the preferred embodiment of the invention has been illustrated and described, it will be appreciated that various changes can be made therein without departing from the spirit and scope of the invention.